Assistive Technology Based on IoT in Building Automation: A Multidisciplinary Engineering Project

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Abstract

Nowadays, most of our daily activities can be performed indoors; according to the U.S. Environmental Protection Agency (EPA), on average, an American spends 90 percent of their life indoors. Although multiple efforts have been made to improve the various aspects of sustainability in living spaces, indoor comfort and efficiency nonetheless require improvement. Therefore, more studies and advancements in efficient building design are vital to improve user comfort, while also addressing the aspects of sustainability. This will help achieve the principles of sustainability without altering user activities and avoiding a resulting negative impact on the environment. The green building evaluation and certification rating system, Leadership in Energy & Environmental Design, LEED®, developed by the United States Green Building Council (USGBC), has been working to change the way that professionals design buildings, develop construction methods, and apply different technologies to positively affect how users perceive and interact with the built environment. This paper presents the importance of exposing undergraduate engineering students to assistive technologies. This has been achieved through the implementation of a project-based learning environment with technology development and the integration of multidisciplinary learning experiences. Engineering technology students collaborate with computer systems engineering students to solve real problems in building automation and assistive technology based on the Internet of Things.

Introduction

The term sustainable development was first introduced to the world during the Brundtland Commission of the United Nations in 1987, defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1]. Therefore, adding the concept of sustainability is often intended to describe the activity’s ability to self-support and continue throughout an extended period, without a significant negative impact on the interconnected activities.

This paper describes the importance of including sustainable practices in the form of assignments in undergraduate engineering education. A project-based learning model, with the use of microcomputers as part of the teaching and learning process, has been developed to provide the students with a hands-on approach to test an assistive automation system. An important learning outcome from this project for the students is to translate the technical information into energy efficient strategies associated with user comfort by providing improvements or modifying the methods of user interaction with the technology required for completing daily tasks.
The paper presents a preliminary description of the importance of sustainability in the built environment. Additionally, it discusses how home automation provides professionals and users multiple methods of technology application and adaptation in order to minimize negative energy consumption impacts while positively affecting the economic and social aspects of the built environment. The importance of a nonintrusive approach to commonly used automation and control systems, including automation and climate, heating, ventilating and air conditioning (HVAC) control, energy control, and lighting control, are also included.

**Background**

The sustainability term associated with building practices and the built environment is evaluated with regard to the following aspects: environmental-friendly practices, comprehensive design, and efficient construction practices. These aspects are often compared to the traditional methods of building, including maintenance and operations. It is clear that there is a long list of concerns to be addressed in order to provide a better solution for incorporating sustainability practices in buildings, that is, through: building performance, building practices, design processes, construction economics, and the surrounding building environment. These items can be covered through the three main elements of sustainable development: economic sustainability, environmental sustainability, and social sustainability.

According to the U.S. Environmental Protection Agency (EPA), on average, an American spends 90 percent of their lifetime indoors. Although multiple efforts toward sustainability have been implemented, indoor comfort and efficiency still requires numerous improvements. Therefore, continuous studies and advancement in efficient building design and user comfort are becoming vital to achieve the principles of sustainability, without altering user activities and avoiding negative environmental impacts.

The advantages of incorporating sustainability practices may be exponentially increased through the use of technology. Economic sustainability carries economic growth, community development and productivity (building and occupants); social sustainability benefits are a reflection of social equity, accessibility, cultural identity translating to convenience, and indoor comfort to improve user quality of life; and environmental sustainability elements, such as carrying capacity, water and energy saving, and green energy sources, are essential when planning for the long-term, as required by sustainable development [2]. Building automation provides an enhanced solution to every one of the three aforementioned elements of sustainable development.

The importance of including sustainable practices in engineering technology curriculum cannot be overemphasized. The engineering technology professionals are performing important roles in
digitally-enriched environments, such as automation for smart homes. In a technologically enhanced environment, the concept of a smart home is explained using a wide variety of definitions, as the term *smart* entails being “automatic, compact, innovative, convenient, self-adjusting, responsive, or functional” [3]. The described structure suggests that *smart homes* can be identified as containing the following features:

- Automation: the ability to accommodate automatic devices or perform automatic functions;
- Multi-functionality: the ability to perform various duties or generate various outcomes;
- Adaptability: the ability to adjust (or be adjusted) to meet the needs of users;
- Interactivity: the ability to interact with or allow for interaction among users; and
- Efficiency: the ability to perform functions in a time-saving, cost-saving and convenient manner. [3]

With the basic features listed above, a brief description of the elements included in a smart home is required, including: network, controlling devices, monitoring system, and automation. A useful explanation of the interaction of the basic features describes that “the network is used for connecting the automation to the controlling devices and it can be wire and wireless. The controlling devices are used for managing the systems. And the home automation are devices which control the physical environment.” [4]

**Methodology**

This multidisciplinary engineering project is a project-based learning activity, planned to introduce the undergraduate engineering students to a series of activities where they must apply the knowledge acquired throughout their coursework, in addition to the automation features of a smart home. Through the use of microcomputers, students are challenged in a hands-on approach, testing their conceptual design and proposed solutions. An important outcome expected from the students is to translate the technical information into energy-efficient, socially aware and environmentally friendly strategies. These strategies should be associated with economic feasibility, user comfort, and environmental impact by providing improvements to, or modifying methods of, user interaction with the technology used to complete daily tasks. The students must present a problem definition and a design statement with a potential engineering solution. Additionally, students will also develop a scaled prototype to evaluate their proposed solution based on its effectiveness and performance.

**Participating programs**

The Engineering Technology (ENGT) Program at The University of Texas Rio Grande Valley (UTRGV) is described as “the profession in which knowledge of mathematics and natural
science, gained by higher education, experience, and practice, is devoted primarily to the implementation and extension of existing technology for the benefit of humanity. Engineering technology education focuses primarily on the applied aspects of science and that portion of the technological spectrum closest to product improvement, industrial practices, and engineering operational functions” [5].

The partner institution, Tecnológico Nacional de México/Instituto Tecnológico de Matamoros (TecNM/ITM) has listed the Computer Systems Engineering (CSE) program as being committed “to train leading, analytical, critical and creative professionals with strategic visions and broad ethical sense, capable of designing, implementing and managing computational infrastructure to provide innovative solutions for the benefit of society, in a global, multidisciplinary and sustainable context” [6].

Therefore, including home automation and inclusive design sets sights on providing the undergraduate student with a dynamic hands-on learning feature that lies within the economic, environmental, and social aspects of sustainability; namely, it is economically feasible, environmentally responsible and socially conscious. Working as a multidisciplinary team, both undergraduate engineering programs are providing students with the opportunity for cross-border collaboration while also promoting international preparedness and industry readiness in this ever-changing, technology-driven world.

Home Automation

A definition of a smart home that simplifies the elements and its final purpose is as follows: “a home which is smart enough to assist the inhabitants to live independently and comfortably with the help of technology is termed as smart home. In a smart home, all the mechanical and digital devices are interconnected to form a network, which can communicate with each other and with the user to create an interactive space” [7]. One of the features of smart homes is the embedded ability to accommodate automatic devices or perform automatic functions [3], and it is catalogued as automation. This capability to computerize a reaction in response to repetitive processes and continuous activities can lead towards the optimization of resources and ultimately the increased efficiency of the technology used, innovating the interaction between the user and the environment for an enhanced experience within the built environment, provided by the interconnection and communication of the located devices.

The progress of non-intrusive sensors technology, wireless communication, and networking has significantly changed the quality of living by the modification of how people live [8][9]; these changes are part of an unprecedented growth of sustainable design practices, in an effort to minimize the cost implications of technology development. Elements such as product life cycle, initial investment, and maintenance and operational costs are of significant importance in the
decision-making of technology adoption. The associated benefits should represent an important add-on to the productivity, energy consumption and long-term efficiency.

Inclusive Design

The practice of awareness in design has now moved far beyond the lone description of needs and aesthetically pleasant results, to embrace the positive value of the three elements of sustainability. There are some topics that remain to be solved prior to acquiring a confirmation of the positive assessment of inclusive design and home automation and its benefits, as defined by Robles and Saisakul, respectively, in the following statements:

Although smart home technologies demonstrate potential benefits in assisting elderly individuals, a successful adoption of such technologies would require a thorough assessment of the need, perception, and concerns of related stakeholders [8], which can be achieved by the use of the Internet of Things (IoT) offering the users with disabilities the assistance and support needed to achieve a good quality of life, allowing them to participate in the social and economic life [10].

Some of the identified benefits that could be offered by smart homes include: improved energy efficiency, improved security, enhanced home appliances, and protection devices to allow the users, namely, the elderly and disabled, to continue living in their own homes [11]. Health monitoring and remote diagnosis can also be included and are an important part of the design of assistive healthcare environments – although a deeper design analysis is required – to select the proper technology.

The 7-level methodology

The 7-level methodology provides a systematic analysis to develop an interface for universal design that involves the understanding of the fundamental interaction. In order to produce an innovative design approach, a 5-level design system was developed, dividing stage 2 of the design into three components to individually define the system. During stage 3, an evaluation process is required to verify and validate the system operability [12]. Figure 1 describes the levels and stages of the 7-level design approach:
This methodology allows professionals involved in every design stage of a project to have an approach for the actual user needs and their perception of what it is needed. Consequently, the
project can be developed to fulfill user expectations with the guarantee of an accurate performance, as a validated system will be implemented according to defined expectations.

**The Green Building Challenge**

Sustainability plays an important role in recent technology developments. An item, product, system or artificial environment must have the ability to provide a solution for user needs; it must not result in an excess burden on the economics and must restrain the direct or indirect negative impacts on the surrounding environment, while creating a positive impact on the quality of life and user comfort. Therefore, we are facing two trends in the market: smart homes and sustainable homes. These terms have been running in diametrically opposing positions, as a smart home entails including Information and Communication Technology (ICTs) and electronic equipment to the built environment; while designing a sustainable building intends to reduce the environmental, economic and social burdens in order to increase efficiency [13], since the design process, including the different construction phases, provides a system for proper building maintenance and operations.

Factors such as the growing electricity usage and the increase of environmental regulations are opening a different market to innovative solutions on the improvement of the built environment. An example of this is the need to improve the overall efficiency of electronic devices [14] typically used in building automation projects.

The first series of developed projects has started using the principles of the 7-level design approach in order to achieve a sustainable outcome (environmentally, economically and socially conscious), following the sensor network technique, which is described as “an environment that enables communications with sensors through the microcontrollers” [15]. Each project should monitor diverse parameters, using assorted sensors, in order to provide the resultant reactions and services. The options of microcontrollers for use include: Raspberry Pi B, Raspberry Pi 3, Arduino UNO R3, Arduino Leonardo, and Arduino MEGA 2560 R3. In specific scenarios, and due to special connectivity conditions, the students are able to use different types of sensors or microcontrollers to validate the system interoperability and prove it to be consistent with the sustainability elements. The list of sensors to use and choose from is as follows:

1. BMP180 Digital Barometric Pressure Sensor Module
2. Buzzer Alarm Sensor Module
3. Digital Touch Sensor Module
4. DHT11 Temperature Sensor Module
5. DS18B20 Temperature Sensor Module
6. Flame Detection Sensor Module
7. HC-SR501 Infrared PIR Motion Sensor Module
8. MQ-1 Gas Smoke Sensor Module
9. MQ-5 Combustible Gas Detector Sensor Module
10. MQ-7 Carbon Monoxide Detector Sensor Module
11. Photosensitive Light Sensor Module
12. Sound Detection Sensor Module
13. Vibration Sensor Module
14. Voltage Detection Sensor Module
15. Water Level Sensor Module.

The data collected with the use of the previously listed sensors, must be sent to the ThingSpeak IoT [16] platform by an MQTT protocol, in order to have the information available in the form of charts, and send alert messages to the users via social media, such as a Twitter message.

The scarcity of information describing the benefits of home automation applications limits the possibilities for innovation; however, users are starting to realize the potential benefits of automation to achieve sustainability goals. As this awareness grows, the demand for networking products for home automation applications will increase [17].

As we are living in the era of information, security issues are important to address, given the possibility of networking and connectivity compromising user privacy. Furthermore, the innovative technology used in home automation could introduce new security gaps not faced before. Thus, an additional opportunity for improvement is the utilization of sensors and networking to address such safety and privacy issues, along with the monitoring and control systems to progressively affect energy conservation [17], [18], [19].

**Lessons learned and future work**

Previous successful attempts in cross-border collaboration between UTRGV-ENGT and TecNM/ITM-CSE, such as the completion of undergraduate engineering senior projects, have supplied the background experience to expand the multidisciplinary team framework into short-term course projects. The strengthening of the learning outcomes through the implementation of this novel structure provides an early response to the undergraduate regional needs in the manufacturing industry, agroindustry, healthcare and wellbeing, and services such as ICTs.

Multidisciplinary engineering projects can broaden their impact by the addition of senior high school students interested in pursuing a career in the STEM field, not only as an outreach effort, but also to make the student aware of their context in addressing the community needs. The ultimate goal for this multidisciplinary team framework is the creation of a comprehensive, cooperative learning environment for undergraduate engineering programs.
As part of this program, the students had the opportunity to present their collaborative work results at the 2018 Texas Regional Alliance for Campus Sustainability, in Stephenville, TX, and at the 2018 UTRGV Engaged Scholar Symposium, in Edinburg, TX. The configuration of the partnership endorses collaborative leadership through the continuous support from different organizations in the community that are committed to educating cross-border leaders. Furthermore, the next foreseen phase is the alignment of particular program objectives to support strategic regional goals.

Additional future projects include the design of a local renewable energy monitoring station, to include green building and solar and wind energy systems studies, where the students will be able to practice the knowledge acquired during their courses, while monitoring the system real-time readings. These types of projects are planned to prepare the students for multidisciplinary engineering interaction and team work, by enhancing abilities such as technical writing, communication, and soft skills.

**Conclusion**

User perception of the complexity of technology usage for home automation represents an important barrier in the analysis of innovative approaches for the implementation of novel sensor network techniques. This condition may be addressed as a topic in education for sustainability in undergraduate engineering programs by adopting the perspective of social sustainability as a strategy for inclusive design.

The objective, while still in development, is to provide a user-friendly, technical environment that allows the user an easy, successful experience without the need for continuous interaction to modify the settings, but instead to have a smart environment that can learn, analyze and provide the service required by the user.

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